

This Page Is Inserted by IFW Operations
and is not a part of the Official Record

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images may include (but are not limited to):

- BLACK BORDERS
- TEXT CUT OFF AT TOP, BOTTOM OR SIDES
- FADED TEXT
- ILLEGIBLE TEXT
- SKEWED/SLANTED IMAGES
- COLORED PHOTOS
- BLACK OR VERY BLACK AND WHITE DARK PHOTOS
- GRAY SCALE DOCUMENTS

IMAGES ARE BEST AVAILABLE COPY.

As rescanning documents *will not* correct images,
please do not report the images to the
Image Problem Mailbox.

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

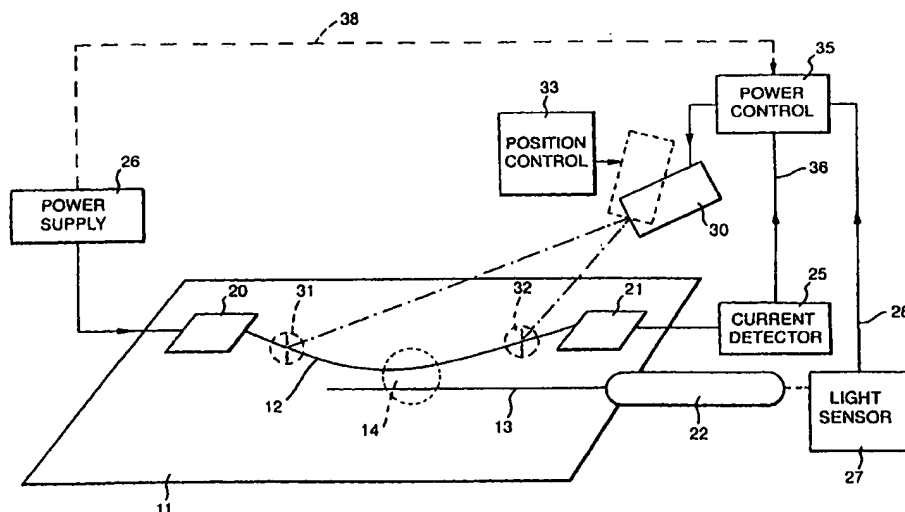


INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁶ : G02B 6/12		A1	(11) International Publication Number: WO 99/63373
			(43) International Publication Date: 9 December 1999 (09.12.99)
(21) International Application Number: PCT/GB99/01768			(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).
(22) International Filing Date: 3 June 1999 (03.06.99)			
(30) Priority Data: 9812036.3 4 June 1998 (04.06.98) GB			
(71) Applicant (for all designated States except US): BOOKHAM TECHNOLOGY LIMITED [GB/GB]; 90 Milton Park, Abingdon, Oxfordshire OX14 4RY (GB).			
(72) Inventors; and (75) Inventors/Applicants (for US only): CORNISH, Andrew [GB/GB]; 3 Hardwick Close, Swindon, Wiltshire SN2 3TR (GB). MCKENZIE, James, Stuart [GB/GB]; Flat 6, 67/69 The Greenway, Uxbridge, Middlesex UB8 2PL (GB).			
(74) Agents: PALMER, Roger et al.; Page White & Farrer, 54 Doughty Street, London WC1N 2LS (GB).			

Published
With international search report.

(54) Title: OPTICAL WAVEGUIDE ATTENUATION



(57) Abstract

A tunable optical transmission circuit has a light source (20) forming an input to a waveguide (12), a detector (21) detecting light output from the waveguide, a comparator for comparing the output with a predetermined value to generate a difference signal and a waveguide trimmer for changing the waveguide transmission in dependence on the difference signal until the output matches the predetermined value. In a preferred embodiment, trimming of the waveguide is effected by use of a trimming laser (30) operated to form a cut (31, 32) in the wall of the optical waveguide.

AH5

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakhstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

OPTICAL WAVEGUIDE ATTENUATION

The invention relates to methods and apparatus for optical waveguide attenuation.

In optical transmission devices including optical waveguides, it may be necessary to measure and modify attenuation in an optical waveguide and the relationship between the operating parameters of devices used at an input and an output of the waveguide. Testing of equipment using such optical waveguides and the setting of input or output equipment depending on the attenuation characteristics may well be costly in both time and expense.

It is an object of the present invention to provide an improved method and apparatus of matching the attenuation of an optical waveguide with the operating characteristics of apparatus used at the input and/or output ends of the waveguide.

The invention provides a method of tuning optical transmission characteristics of an optical transmission circuit including an optical waveguide, which method comprises supplying light to an input of the waveguide, detecting the amount of output light emitted from the waveguide, comparing the light output with a predetermined value of output to generate a difference signal, driving a waveguide trimmer to change the waveguide transmission characteristics at a selected position along the waveguide, said driving of the waveguide trimmer being responsive to the difference signal so that the waveguide trimmer is operated to continue change in the transmission characteristics while detecting the amount of light output until the light output value matches said predetermined value.

Said predetermined value may be set in dependence on an input value of a light source used to provide the light input to the waveguide.

Conveniently trimming of the waveguide is effected by use of a

trimming laser operated to form a cut in the waveguide. Devices other than a laser may be used.

The cut may be acute angle to the length of the waveguide to reduce reflection towards the input of the waveguide.

Preferably the waveguide is formed in an integrated silicon chip.

The waveguide may be formed as a rib in a silicon layer formed over a layer of silicon dioxide.

The waveguide may form part of an optical transmission path between a light source and an optical fibre, said detecting of output light comprising detecting light entering said optical fibre.

The trimming of the waveguide may be effected to result in a desired value of output light in the optical fibre relative to an input value operating the light source.

The waveguide may form part of an optical transmission path between a light source and a monitor device for monitoring light output from the light source.

The trimming of the waveguide may be effected to result in a desired value of monitor output signal relative to an input value operating the light source.

Preferably said monitor device comprises a photodiode.

Conveniently the input to the waveguide is generated by a laser device having a light output related to an electrical input signal supplied to the laser.

Preferably said waveguide forms part of a waveguide network connecting a light source to both an optical fibre and to a monitor device, said method comprises trimming one waveguide

region in dependence on light detected at the optical fibre to obtain a desired value of light entering the fibre, and trimming a different waveguide region which leads to the monitor but is independent of the path to the optical fibre, thereby obtaining a desired output from the monitor.

Conveniently the waveguide network includes a first waveguide region forming a common path to both the optical fibre and the monitor and a second region which provides independent transmission paths to the monitor and to the optical fibre, said method including forming one trimming in the first waveguide region and a second trimming in said second waveguide region.

- In one embodiment said first waveguide region is formed by a part of a first waveguide and said second waveguide region comprises two independent optical paths, one being formed as an extension of said first waveguide and the second being formed by a second waveguide optically coupled to the first waveguide.

The invention also provides apparatus for tuning the optical transmission characteristics of an optical transmission circuit including an optical waveguide, which apparatus comprises a power supply for connection to a light source which forms an input to an optical waveguide, a light level detector for detecting output light emitted from the waveguide, a comparator for comparing the light output with a predetermined value to generate a difference signal, a waveguide trimmer for changing the waveguide transmission characteristics at a position intermediate the ends of the waveguide, and drive circuitry for operating the waveguide trimmer, said drive circuitry being coupled to said comparator and arranged to operate the waveguide trimmer until the light output value matches said predetermined value.

The apparatus may be arranged for trimming a waveguide network interconnecting a light source with an optical fibre and a monitor, which apparatus comprises a first detector for detecting a light level reaching the optical fibre, a second detector for

detecting an output signal level from the monitor, control circuitry responsive to output signals from the first and second detectors and comparing them with predetermined values and drive circuitry responsive to an output of said control circuitry for operating a trimming laser for effecting two trimming operations in the waveguide network in order to achieve required levels both for the output of the monitor and light entering the optical fibre.

An embodiment of the invention will now be described by way of example and with reference to the accompanying drawings in which:

Figure 1 is a schematic view of one embodiment of the invention for use in varying the attenuation of an optical waveguide,

Figure 2 shows in more detail a waveguide structure which may be used in the apparatus of Figure 1,

Figure 3 shows one form of cut which may be formed in a waveguide trimming operation in use of the apparatus of Figure 1, and

Figure 4 shows an alternative cut which may be used in a trimming operation in use of the apparatus of Figure 1.

The embodiment shown in Figure 1 relates to the tuning of optical attenuation in a waveguide formed on a substrate which may be a silicon-on-insulator chip 11. The waveguide forms part of a waveguide network consisting of a first waveguide 12 and a second waveguide 13. The two waveguides are optically coupled in a region 14. Each of the waveguides 12 and 13 is formed as a single mode silicon waveguide structure consisting of a rib 15 as shown in Figure 2. The chip 11 is formed as a monolithic structure having a silicon substrate 16 covered by a silicon dioxide layer 17. A further silicon layer 18 extends into the rib 15 with a silicon dioxide coating 19 extending over the silicon 18.

Mounted on the chip 11 is a light source 20 in the form of an electrically driven laser diode as well as a photodiode 21 acting as a monitor by producing an output current depending on the light generated by the laser 20. An external optical connection from the chip is provided by an optical fibre 22. The chip may act as a light transmitter for light which is generated by the laser 20 and output through the fibre 22. In that case light from the source 20 passes firstly through the waveguide 12 and then through the optical coupling 14 into the second waveguide 13 before being output through the fibre 22. The chip may also act as a receiver in which case light received through the fibre 22 will be directed along the waveguide 13 and may be received by a light detector (not shown) coupled to an end of the waveguide 13 from the fibre 22.

To monitor the light output from the laser 20, light is directed along the waveguide 12 to the photodiode 21 which generates an output current detected by a current detector 25. The power to the laser 20 is determined by an adjustable power supply 26. When the chip is being used to output light, light passing through the fibre 22 from the light source 20 is detected by a light sensor 27 which provides a signal on line 28 indicating the amount of light entering the fibre 22.

Due to variations in the operating characteristics of the laser 20 and the photodiode 21 as well as variations in the attenuation in the waveguides 12 and 13, considerable variations may occur in the relationship between currents detected by the current detector 25 for a given electrical supply to the laser 20 and similarly considerable variations occur in the light entering the fibre 22 in relation to the selected power supply for the laser 20. This embodiment provides apparatus and a method for tuning products so as to achieve accurate relationships between drive supply for the laser 20 and the output of a photodiode 21 as well as for the relationship between the drive supply to the laser 20 and the amount of light entering the fibre 22. This allows for substantially increased yield for a predetermined set of

specifications in products by tuning the waveguide attenuation to permit the desired relationships between the laser input and the two outputs referred to above.

A trimming laser 30 is provided to trim the attenuation of the waveguide 12 by forming cuts in the rib at positions marked 31 and 32 in Figure 1. The position of the trimming laser 30 can be varied as shown under the control of a position control unit 33. Power to the trimming laser 30 is varied under the control of a power control 35 arranged to receive an input from line 28 as well as an input on line 36 from the current detector 25. The power control unit 35 may also be responsive to the setting of the laser power supply 26 by a signal indicated on broken line 38. The wavelength of radiation from the trimming laser 30 is sufficiently different from that of the laser 20 so that light from the trimming laser 30 does not supplement the detected level of light transmitted through the waveguide to either the optic fibre or photo diode.

In use, laser 20 is powered with a preset driving current from the power supply 26. The amount of light entering the fibre 22 is detected by the light sensor 27. The power control 35 compares the signal on line 28 in relation to the power supply setting detected from line 38. It then operates the laser 30 which is directed by the position control 33 so that the trimming beam from the laser impinges on waveguide 12 at position 31. So long as the power control 35 senses a difference between the signal level on line 28 and a predetermined level required for light in the fibre 22, laser 30 will continue to cause damage to the waveguide 12 in the region 31 until the signal on line 28 reaches the required level corresponding to a required ratio of input current to the laser 20 and light output through the fibre 22. The laser 30 is then switched off. At that point the position control 33 adjusts the position of laser 30 so that the laser beam is directed to the region 32 on waveguide 12. The value of monitor current in line 36 is then sensed by the power control 35 and compared with a preset value in relation to the

drive current of the laser 20. If a difference is detected then the power control 35 switches on laser 30 to trim the attenuation of waveguide 12 in region 32. The trimming is continued while continuing to sense the monitor current on line 36 until the monitor current indicates that the output of the photodiode 21 has the correct ratio with the input current of the laser 20. At that point the laser 30 is switched off. The product has then been tuned to provide the correct ratio of output signals both from the monitor 21 and the fibre 22 in relation to the drive current used for the light source laser 20.

The laser 30 may be arranged to form a cut 40 as indicated in Figure 3 which extends at right angles across the length of the rib 15. Alternatively the laser 30 may be directed at the waveguide 12 so as to produce an angled cut 41 as shown in Figure 4. In this case the cut 41 extends transversely across the rib 15 at an acute angle relative to a line 42 perpendicular to the length of the rib 15. With such an angled cut formed in the waveguide wall, light reflected towards the laser source 20 is reduced. The cut may be formed across the top of the rib or alternatively in the side wall of the rib.

It will be seen that by effecting two laser trimming operations in sequence, the first trimming at location 31 affects the attenuation of light passing both to the photodiode 21 and to the optic fibre 22. Once attenuation has been carried out at point 31 to achieve the correct output through the fibre 22 it is necessary that the second trimming operation at region 32 affects only the light passing to the photodiode 21 and does not cause any further change in the light reaching the fibre optic 22.

The invention is not limited to the details of the foregoing example. For instance, instead of cuts as shown in Figures 3 and 4 other waveguide damage, such as abrasion, may be used to vary the transmission through the waveguide. Such abrasion may result from laser damage to the substrate close to the waveguide.

Although the example illustrates an integrated silicon on insulator structure for formation of the waveguide, other structures may be used. Instead of a rib waveguide, a buried guide may be formed. The invention may be used on both transmitters and receivers of light and may be used in other optical planar waveguide circuits to control variation in attenuation through an optical transmission circuit incorporating a waveguide. It may be used in the final test of attenuators, dense wavelength division multiplexors and multiway transmitters. Instead of using a trimming laser 30 other trimming techniques to vary the attenuation may include optical, chemical, mechanical and focused energy techniques.

All the above described embodiments provide a method of actively tuning attenuation in a waveguide circuit while continuing to monitor light received at an output from the waveguide. The light detection at the output is tuned to detect only the radiation wavelength of the laser source 20 and not to include any light of the wavelength used by the trimming laser 30.

In the example of Figure 1 the first trimming operation to vary the light transmitted to the detector 27 is carried out on the waveguide 12 in the region 31. However, as an alternative, this first trimming operation may be carried out on waveguide 13 leading to the optic fibre 22.

The light source used may be a light emitting diode (LED device) in place of the laser 20.

CLAIMS:

1. A method of tuning optical transmission characteristics of an optical transmission circuit including an optical waveguide, which method comprises supplying light to an input of the waveguide, detecting the amount of output light emitted from the waveguide, comparing the light output with a predetermined value of output to generate a difference signal, driving a waveguide trimmer to change the waveguide transmission characteristics at a selected region along the waveguide, said driving of the waveguide trimmer being responsive to the difference signal so that the waveguide trimmer is operated to continue change in the transmission characteristics while detecting the amount of light output until the light output value matches said predetermined value.

2. A method according to claim 1 in which said predetermined value is set in dependence on an input value of a light source used to provide the light input to the waveguide.

3. A method according to claim 1 or claim 2 in which trimming of the waveguide is effected by use of a trimming laser operated to form a cut in a wall of the waveguide.

4. A method according to claim 3 in which the cut is at an acute angle to the length of the waveguide to reduce reflection towards the input of the waveguide.

5. A method according to any one of claims 1 to 4 in which the waveguide is integrated on a substrate.

6. A method according to claim 5 in which the substrate is a silicon chip.

7. A method according to claim 5 in which the waveguide is formed as a rib in a silicon layer formed over a layer of silicon dioxide.

8. A method according to any one of the preceding claims in which the waveguide forms part of an optical transmission path between a light source and an optical fibre, said detecting of output light comprising detecting light entering said optical fibre.

9. A method according to claim 8 in which the trimming of the waveguide is effected to result in a desired value of output light in the optical fibre relative to an input value operating the light source.

10. A method according to any one of the preceding claims in which the waveguide forms part of an optical transmission path between a light source and a monitor device for monitoring light output from the light source.

11. A method according to claim 10 in which the trimming of the waveguide is effected to result in a desired value of monitor output signal relative to an input value operating the light source.

12. A method according to claim 10 or claim 11 in which said monitor device comprises a photodiode.

13. A method according to any one of the preceding claims in which the input to the waveguide is generated by a laser device having a light output related to an electrical input signal supplied to the laser.

14. A method according to any one of claims 1 to 12 in which the light source forming an input to the waveguide is an LED device.

15. A method according to any one of the preceding claims in which said waveguide forms part of a waveguide network connecting a light source to both an optical fibre and to a monitor device, said method comprises trimming one waveguide region in dependence on light detected at the optical fibre to obtain a desired value

of light entering the fibre, and trimming a different waveguide region which leads to the monitor but is independent of the path to the optical fibre, thereby obtaining a desired output from the monitor.

16. A method according to claim 15 in which the waveguide network includes a first waveguide region forming a common path to both the optical fibre and the monitor and a second region which provides independent transmission paths to the monitor and to the optical fibre, said method including forming one trimming in the first waveguide region and a second trimming in said second waveguide region.

17. A method according to claim 16 in which said first waveguide region is formed by a part of a first waveguide and said second waveguide region comprises two independent optical paths, one being formed as an extension of said first waveguide and the second being formed by a second waveguide optically coupled to the first waveguide.

18. Apparatus for tuning the optical transmission characteristics of an optical transmission circuit including an optical waveguide, which apparatus comprises a power supply for connection to a light source which forms an input to an optical waveguide, a light level detector for detecting output light emitted from the waveguide, a comparator for comparing the light output with a predetermined value to generate a difference signal, a waveguide trimmer for changing the waveguide transmission characteristics at a position intermediate the ends of the waveguide, and drive circuitry for operating the waveguide trimmer, said drive circuitry being coupled to said comparator and arranged to operate the waveguide trimmer until the light output value matches said predetermined value.

19. Apparatus according to claim 18 for trimming a waveguide network interconnecting a light source with an optical fibre and a monitor, which apparatus comprises a first detector for

detecting a light level reaching the optical fibre, a second detector for detecting an output signal level from the monitor, control circuitry responsive to output signals from the first and second detectors and comparing them with predetermined values and drive circuitry responsive to an output of said control circuitry for operating a trimming laser for effecting two trimming operations in the waveguide network in order to achieve required levels both for the output of the monitor and light entering the optical fibre.

1/2

Fig.1.

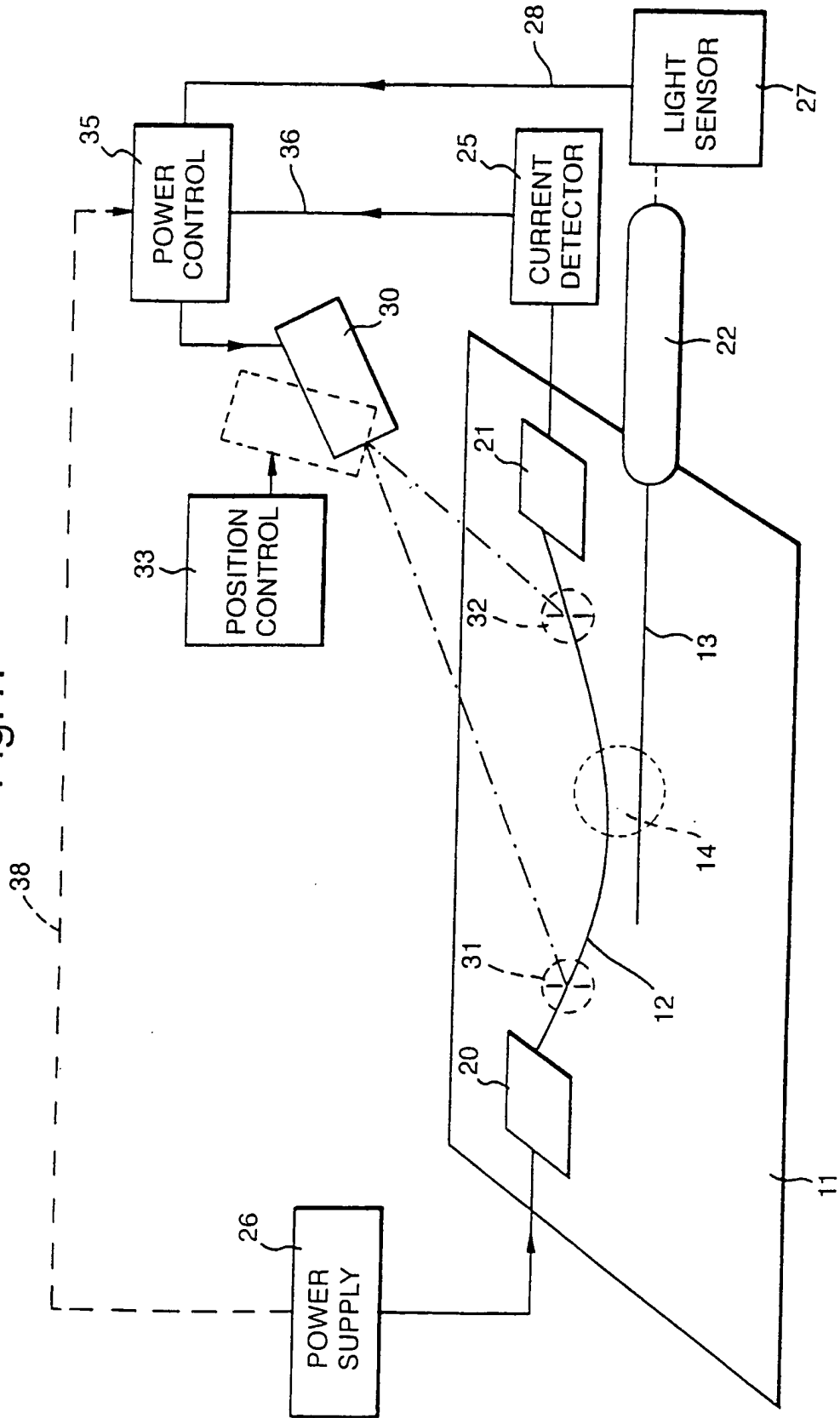


Fig.2.

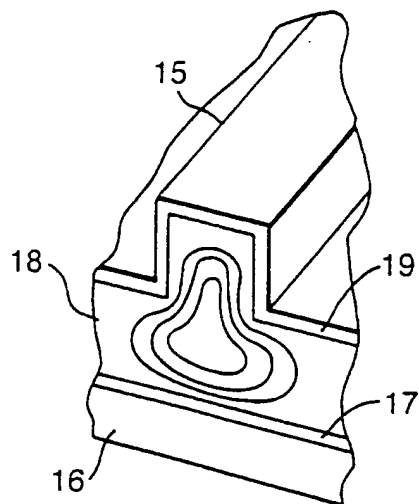


Fig.3.

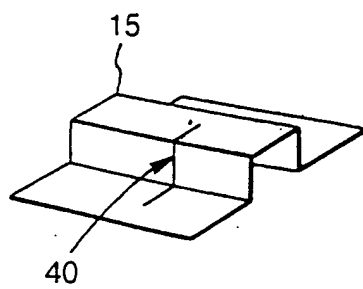
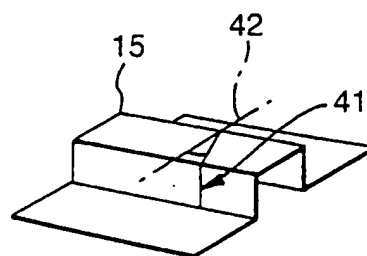


Fig.4.



INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 99/01768

A. CLASSIFICATION OF SUBJECT MATTER

IPC 6 G02B6/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 G02B B23K C03C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CHEN A ET AL: "TRIMMING OF POLYMER WAVEGUIDE Y-JUNCTION BY RAPID PHOTOBLEACHING FOR TUNING THE POWER SPLITTING RATIO" IEEE PHOTONICS TECHNOLOGY LETTERS, vol. 9, no. 11, 1 November 1997 (1997-11-01), pages 1499-1501, XP000722983 ISSN: 1041-1135	1,5,6,8, 10-13,18
A	page 1499, right-hand column, last paragraph - page 1500; figure 2 --- -/--	3,16,17, 19

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"a" document member of the same patent family

Date of the actual completion of the international search

2 September 1999

Date of mailing of the international search report

10/09/1999

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Ciarrocca, M

INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 99/01768

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 5 118 923 A (FARINA JAMES D) 2 June 1992 (1992-06-02) column 5, line 18 - column 6, line 45; figures 5,6 ---	1,2,5, 10-13,18 3
X A	US 5 673 344 A (LI YAO ET AL) 30 September 1997 (1997-09-30) column 4, line 21 - line 54; figure 2 ---	1,8,18 3
X A	PATENT ABSTRACTS OF JAPAN vol. 007, no. 212 (P-224), 20 September 1983 (1983-09-20) & JP 58 107504 A (FUJITSU KK), 27 June 1983 (1983-06-27) abstract ----- US 5 195 163 A (BURNS WILLIAM K ET AL) 16 March 1993 (1993-03-16) column 2, line 28 - column 3, line 14; figure 1 -----	1,10-13, 18 1,3,18

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/GB 99/01768

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 5118923	A	02-06-1992	NONE	
US 5673344	A	30-09-1997	CN 1202629 A	23-12-1998
			EP 0814352 A	29-12-1997
			JP 10054920 A	24-02-1998
JP 58107504	A	27-06-1983	NONE	
US 5195163	A	16-03-1993	US 5259061 A	02-11-1993